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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : G10L 21/02 — A1

(11) International Publication Number: WO 00/38180

(43) International Publication Date: 29 June 2000 (29.06.00)

(21) International Application Number: PCT/SE99/02258

(22) International Filing Date: 3 December 1999 (03.12.99)

(30) Priority Data:
09/215,355 18 December 1998 (18.12.98) US

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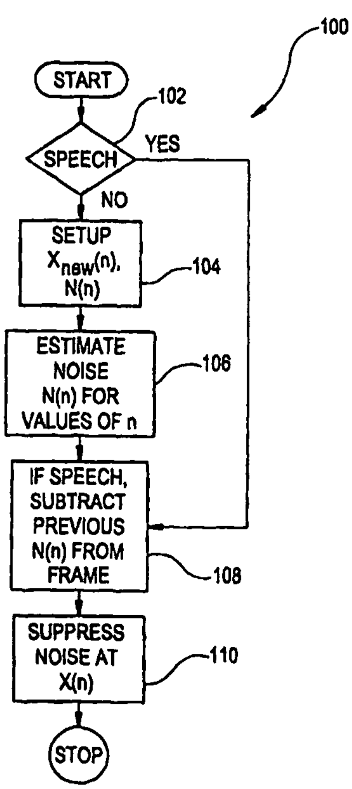
(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: NOISE SUPPRESSION IN A MOBILE COMMUNICATIONS SYSTEM

(57) Abstract

A method and apparatus are disclosed for suppressing bumblebee noise in a mobile communications system, whereby a digital processor (18) associated with a speech coder (17) in a mobile phone (16) receives the incoming stream of speech samples and performs a Fast Fourier Transform on the incoming sample stream. A priori knowledge about where in the frequency spectrum the bumblebee noise occurs is advantageously used to determine just which frequency samples in the Fast Fourier Transform the bumblebee noise has enhanced. The noise at these frequencies is then suppressed (110) by, for example, interpolating between two neighboring frequency samples to suppress the noise in the samples therebetween.



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NOISE SUPPRESSION IN A MOBILE COMMUNICATIONS SYSTEM

BACKGROUND OF THE INVENTION

Technical Field of the Invention

The present invention relates in general to the cellular telephony field and, in particular, to a method and apparatus for suppressing the effects of noise in digital mobile communications systems.

Description of Related Art

The so-called "bumblebee" sound associated with certain mobile phones is noise generated by the switching nature of Time Division Multiple Access (TDMA) cellular telephony. For example, in the Global System for Mobile Communications (GSM), the TDMA radio circuits are switched on and off at a rate of approximately 217 Hz. Signals at this base frequency and its harmonic frequencies are coupled into the analog microphone signal in the mobile phone, which produces the annoying bumblebee noise in the speech signal on the uplink.

In existing radiotelephone or cellular systems, this bumblebee noise is suppressed using various analog noise suppression techniques. For example, bumblebee noise can be suppressed by electrically decoupling certain radio circuits, or by using certain microphones designed to minimize the noise. Also, certain digital techniques (e.g., digital noise canceller) could be used to suppress bumblebee noise. However, at present, these conventional devices and approaches would function minimally at best, because they estimate the noise without making use of prior knowledge of the disturbing frequencies. As such, the above-described conventional approaches and devices for suppressing bumblebee noise are time-consuming, require costly components, and they are exceptionally difficult to implement. These approaches and devices can also require the use of non-optimal system settings such as, for example, compensating offsets in microphone gain.

An analysis of a Fourier expansion of a disturbing periodic signal that

creates bumblebee noise illustrates that the frequency components of this signal decay at the rate of 1/frequency, which is a relatively slow rate. Consequently, it is not effective to filter out only the first few frequency components of the disturbing signal, because there are approximately 15 frequency components that have to be suppressed in the frequency band below 4 kHz. Therefore, if a conventional notch filter design were to be considered for bumblebee noise suppression, the computational complexity of employing 15 notch filters would serve as a significant deterrent at best. However, as described in detail below, the present invention successfully resolves these and other related noise suppression problems.

SUMMARY OF THE INVENTION

In accordance with a preferred embodiment of the present invention, a method and apparatus for suppressing bumblebee noise in a cellular system are provided, whereby a digital processor associated with a speech coder in a mobile phone receives the incoming stream of speech samples and performs a Fast Fourier Transform (FFT) on the incoming sample stream. A priori knowledge about where in the frequency spectrum the bumblebee noise occurs is advantageously used to determine just which frequency samples in the FFT the bumblebee noise has enhanced. The noise at these frequencies is then suppressed by, for example, interpolating between two neighboring frequency samples to suppress the noise in the samples therebetween.

An important technical advantage of the present invention is that bumblebee noise in mobile communications systems can be suppressed at the expense of only a slight increase in current consumption in a digital signal processor (DSP), but at no additional cost for components, etc.

Another important technical advantage of the present invention is that it provides an approach for suppressing bumblebee noise in mobile communications systems that can supplement conventional approaches or devices being used.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the method and apparatus of the present

invention may be had by reference to the following detailed description when taken in conjunction with the accompanying drawings wherein:

FIGURE 1 is a block diagram of an exemplary mobile radiotelephone which can be used to implement a preferred embodiment of the present invention;

FIGURE 2 is an exemplary diagram of a noise signal in the frequency plane, which is infected with a periodic disturbance at known frequencies; and

FIGURE 3 is a flow diagram of an exemplary algorithm or method that can be used to implement the preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE DRAWINGS

The preferred embodiment of the present invention and its advantages are best understood by referring to FIGUREs 1-3 of the drawings, like numerals being used for like and corresponding parts of the various drawings.

Essentially, in accordance with a preferred embodiment of the present invention, a method and apparatus for suppressing bumblebee noise in a cellular system are provided, whereby a digital processor associated with a speech coder in a mobile phone receives the incoming stream of speech samples and performs an FFT on the incoming sample stream. A priori knowledge about where in the frequency spectrum the bumblebee noise occurs is advantageously used to determine just which frequency samples in the FFT the bumblebee noise has enhanced. The noise at these frequencies is then suppressed by, for example, interpolating between two neighboring frequency samples to suppress the noise in the samples therebetween.

Specifically, FIGURE 1 is a block diagram of an exemplary mobile radiotelephone 10, which can be used to implement a preferred embodiment of the present invention. For this exemplary embodiment, the radiotelephone 10 shown in FIGURE 1 is preferably a mobile phone (e.g., mobile station, mobile terminal, etc.) for use in a digital TDMA cellular communications system, such as, for example, the GSM in Europe, the Personal Digital Cellular (PDC) System in Japan, or the Digital-Advanced Mobile Phone System (D-AMPS) in North America. However, the present invention is not intended to be limited to any particular system, but can be applied in any type of communications system where suppression of bumblebee noise or similar

types of noise are at issue.

As shown, the mobile phone 10 includes a transmitting part and receiving part. For this embodiment, the present invention is preferably implemented in the transmitting part of the mobile phone. Consequently, the following description is directed to the transmitting part of the phone. As such, an analog speech signal from the microphone 12 is digitized by an analog-to-digital (A/D) converter 14. A segmentation unit 16 divides the digitized speech signal into 20 ms segments, which are coupled to the speech coder 17. A function of the speech coder 17 is to reduce the bit rate of the digitized speech signals, in order for the resulting speech channels to be able to stay within the allowed frequency band. The bit rates shown are per physical channel.

For the preferred embodiment, a Digital Signal Processor (DSP) or similar type of digital processor 18 is associated with the speech coder 17 to receive the incoming stream of speech samples (e.g., sampled by the coder at 8 kHz). The processor 18 performs an FFT on the incoming sample stream. An exemplary algorithm that can be used to perform such an FFT is described in more detail below. For this embodiment, an FFT block length of, for example, N=256 can be assumed. For this particular block length (N), the separation or distance between speech samples in the frequency domain is approximately 30 Hz. In accordance with the present invention, a priori knowledge about where in the frequency spectrum the bumblebee noise occurs is advantageously used to determine just which frequency samples in the FFT the bumblebee noise has enhanced. For example, the bumblebee noise is enhanced at frequency multiples of 217 Hz = 1/4.615 ms (the access rate in the GSM). The noise at these frequencies is then suppressed (e.g., by interpolating between two neighboring frequency samples to suppress the noise in the samples therebetween). An exemplary algorithm that can be used for suppressing the bumblebee noise at these frequencies is described below. The processor 18 can then perform an Inverse FFT (IFFT) to transform the noise-suppressed speech signals back to the time domain. The speech signals are then channel coded (19), interleaved, encoded and burst formatted (20), modulated (22) and transmitted from the phone 10 over the uplink channel(s).

More precisely, if the processor 18 uses a 256-point FFT for example, then 256

frequency components that are affected by the periodic disturbing noise signal are known. FIGURE 2 is an exemplary diagram of a noise signal in the frequency plane, which shows the noise signal "infected" with a periodic disturbance at known frequencies. Note, however, that the diagram in FIGURE 2 is provided for illustrative purposes only and is not based on actual data. The signal shown comprises a typical noise signal and a periodic disturbance. For simplicity, only the points 1-127 are shown in FIGURE 2, because the points 128-256 are no more than a mirror image of the points 1-127. As such, with an exemplary sampling rate of 8 kHz, the frequency separation between the points in the FFT (as shown in FIGURE 2) is 8000/256 = 31.25 Hz.

Given the above-described conditions, it is known that the disturbance frequencies will occur in the FFT frequency bins n*217/31.25, where n=1,2,3,...etc. Consequently, as illustrated by FIGURE 2, the FFT frequency bins for this example are at 7, 14, 21,..., etc. Also, as illustrated by FIGURE 2, according to the Fourier expansion of the periodic signal, the power of the harmonics will decay at a certain rate.

FIGURE 3 is a flow diagram of an exemplary algorithm or method 100 that can be used to implement the preferred embodiment of the present invention. First, let "X(n)" represent an FFT of an input speech signal to the DSP or digital processor 18, and "N(n)" represent a noise estimate. At step 102 of the method shown in FIGURE 3, the processor 18 determines whether the frame of samples contains only noise (i.e., no speech signal). A reason for this condition is that the verbalized speech (vowels) contains frequency components that can be interpreted improperly as bumblebee noise. A conventional speech coder may be used to provide a voice or speech detection algorithm, in order to ensure that only noise is present when the FFT is performed.

If at step 102, the incoming frame of samples contains a speech signal, the processor 18 does not update the noise estimate in accordance with the subsequent steps. Otherwise, at step 104, the processor 18 sets up the following expressions, $X_{new}(n)=(X(n-1)+X(n+1))/2$, and $N(n)=X(n)-X_{new}(n)$, for the frequency components described earlier (e.g., where n = 7, 14, 21,..., etc.). In other words, for this

embodiment, the processor 18 can use interpolation to form a new value for the noise's spectral component from two adjacent frequency bins (e.g., $X_{new}(7)=(X(8)+X(6))/2$). At step 106, the processor 18 estimates the noise N(n) as $N(7)=X(7)-X_{new}(7)$, and repeats this estimation for the noise frequencies involved (e.g., n = ...14, 21,..., etc.). Returning to step 102, if speech is contained in a frame being processed, at step 108, the processor 18 subtracts the previous noise estimate from that speech frame (e.g., $X_{new}(n)=X(n)-N(n)$, for n = 7, 14, 21,..., etc.). As such, in accordance with the present invention, the discrete values for X(n) provided by the above-described method represent the frequency locations where the bumblebee noise can be and is effectively suppressed (step 110).

Although a preferred embodiment of the method and apparatus of the present invention has been illustrated in the accompanying Drawings and described in the foregoing Detailed Description, it will be understood that the invention is not limited to the embodiment disclosed, but is capable of numerous rearrangements, modifications and substitutions without departing from the spirit of the invention as set forth and defined by the following claims.

WHAT IS CLAIMED IS:

1. A method for suppressing noise in a mobile radiotelephone, comprising the steps of:

receiving a plurality of signal samples from a microphone;

performing a Fast Fourier Transform on said plurality of signal samples;

determining a plurality of frequency locations associated with said Fast Fourier Transform where said noise occurs; and

suppressing said noise at one or more of said plurality of frequency locations.

2. The method of Claim 1, wherein the suppressing step comprises interpolating between a plurality of frequencies adjacent to said one or more of said plurality of frequency locations.

3. The method of Claim 1, wherein said mobile radiotelephone comprises a digital mobile radiotelephone.

4. The method of Claim 1, wherein said mobile radiotelephone comprises a GSM mobile phone.

5. A method for suppressing noise in a mobile communications system, comprising the steps of:

determining whether an incoming set of samples from a microphone contains no speech signal;

if so, performing a Fast Fourier Transform on said incoming set of samples by deriving a first expression $X_{new}(n)=(X(n-1)+X(n+1))/2$ and a second expression $N(n)=X(n)-X_{new}(n)$, for n multiplied by a system access rate and divided by a sampling rate further divided by a plurality of points associated with said Fast Fourier Transform, n being set equal to a predetermined series of numbers;

estimating a noise signal N(n) for each of a plurality of noise frequencies associated with said plurality of points; and

suppressing said noise at one or more of said plurality of points.

6. A mobile telephone, comprising:

a converter for converting a plurality of analog signals from a microphone to a set of digitized signal samples; and

a digital processor coupled to said converter, said digital processor operable to:

perform a Fast Fourier Transform on said plurality of digitized signal samples;

determine a plurality of frequency locations associated with said Fast Fourier Transform noise occurs; and

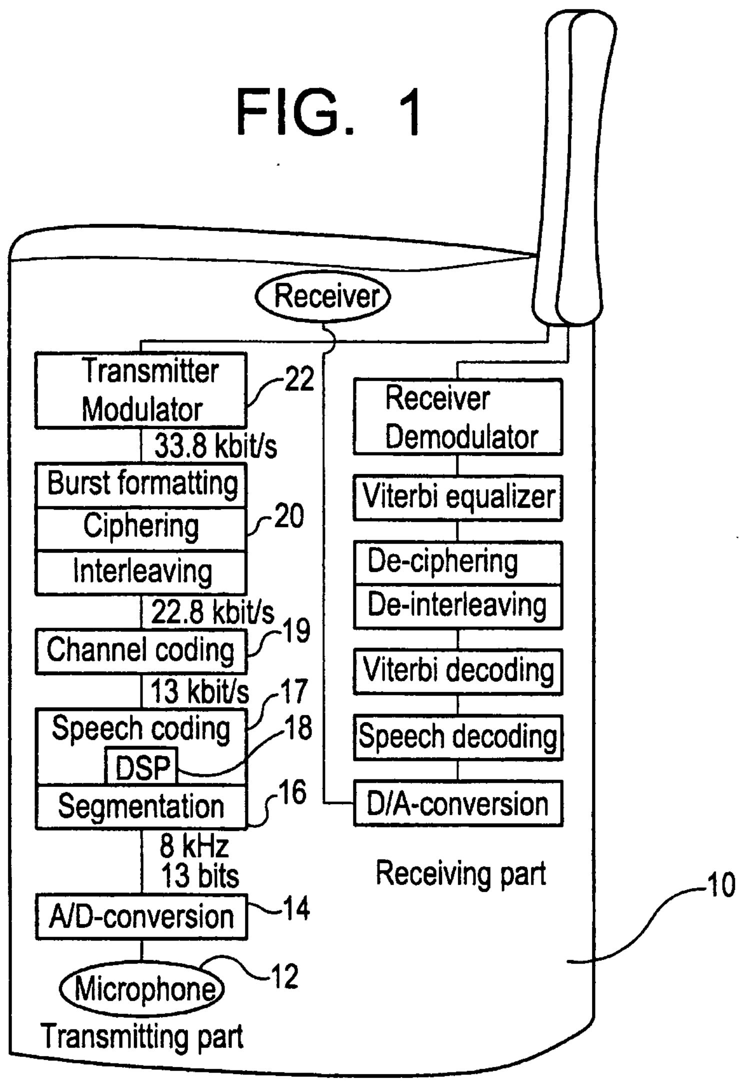
suppress said noise at one or more of said plurality of frequency locations.

7. The mobile telephone of Claim 6, wherein the digital processor is operable to suppress said noise by interpolating between a plurality of frequencies adjacent to said one or more of said plurality of frequency locations.

8. The mobile telephone of Claim 6, which comprises a digital mobile radiotelephone.

9. The mobile telephone of Claim 6, which comprises a GSM mobile phone.

FIG. 1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Burst formatting
Ciphering
Interleaving
20
22.8 kbit/s
Channel coding
19
13 kbit/s
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Speech coding
DSP
18
Segmentation
16
8 kHz
13 bits
A/D-conversion
14
Microphone
12
Transmitting part
Receiver Demodulator
Viterbi equalizer
De-ciphering
De-interleaving
Viterbi decoding
Speech decoding
D/A-conversion
Receiving part
10

FIG. 2

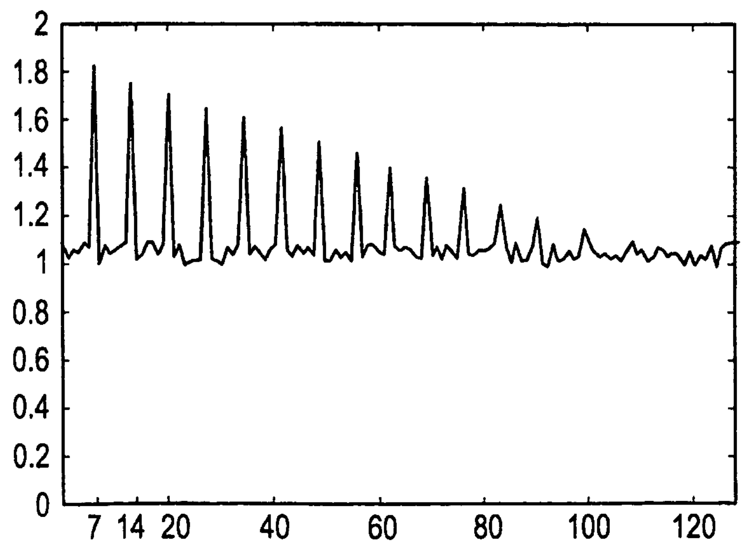
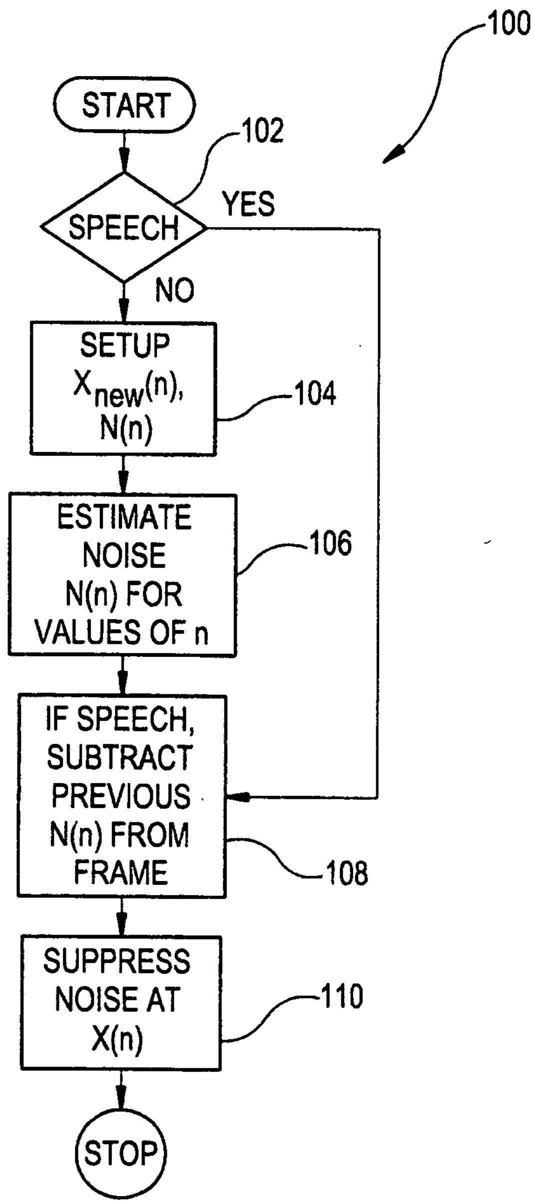

2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
7 14 20 40 60 80 100 120

FIG. 3


100
START
102
SPEECH
YES
NO
SETUP
$X_{new}(n)$,
N(n)
104
ESTIMATE
NOISE
N(n) FOR
VALUES OF n
106
IF SPEECH,
SUBTRACT
PREVIOUS
N(n) FROM
FRAME
108
SUPPRESS
NOISE AT
X(n)
110
STOP